



Figure 27—American marten using a broom rust in Engelmann spruce as a resting site.



Figure 28—Spruce broom rust on Engelmann spruce.



Figure 29—Brooms caused by spruce broom rust are most conspicuous during the summer when yellow-brown spores are present.



Figure 30—Broom formed by *Elytroderma deformans* on ponderosa pine.



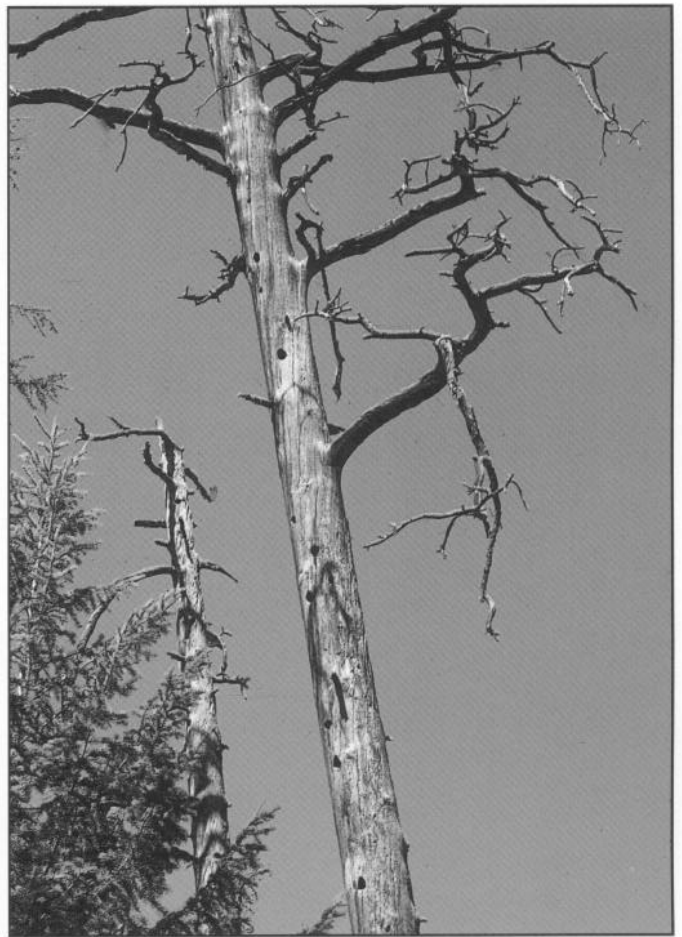
Figure 31—*Elytroderma* broom used by great horned owls for nesting.



Photo by Craig Schmitt

Figure 32—Discolored needles with narrow black fruiting bodies are found in *Elytroderma* brooms.

DEAD TREES



Ecological Processes and Functions

Snags, or standing dead trees, are an essential component in forests, and many wildlife species depend on them for survival. Patches or even entire stands of trees have died across the landscape throughout the evolutionary history of forest ecosystems. The events and decay processes that create these dead trees maintain the snag resource through time.

Several factors or combinations of factors can be responsible for tree mortality, including insect outbreaks, diseases, fire, drought, and flooding. How the tree dies can determine its use by wildlife. Any snag can be used as a perch site, but for a snag to be a suitable site for a cavity, the wood typically must be softened by decay (fig. 33). Some sources of tree mortality are more conducive to the introduction of decay than others. For example, fire can case-harden snags and make them resistant to decay.

Specific types of mortality agents, such as fire, disease, or insects, may target different tree species and age classes; thus a mix of snag species and sizes occurs across the landscape. Although each wildlife species usually has a tree species preference for foraging or nesting, it often uses a variety of tree species. The wildlife not adapted to using a variety of snag species are also those that are most restricted in range and in the greatest danger of extirpation.

Many wildlife species depend on dead trees for nesting, roosting, denning, foraging, resting, or shelter. Woodpeckers and nuthatches, known as primary cavity nesters, have the ability to excavate cavities in snags where they nest and roost (figs. 34 and 35). Because woodpeckers usually excavate a new nest cavity each year, old nest cavities are available for many secondary cavity users. Secondary cavity users, which include many species of birds and mammals, cannot excavate a cavity but use existing ones for nesting, denning, or shelter. Thomas and others (1979) list species that use snags and logs in the Blue Mountains in northeastern Oregon.

The space behind loose bark on snags also provides nest sites for brown creepers (*Certhia americana*) and roost sites for bats. Brown creepers wedge a nest of grass and twigs in the space between the bole and its loose bark. Loose bark also provides bats with a dry, sheltered roosting place (fig. 36). Although bats roost under loose bark, recent studies have shown that a high percentage of bat roosts are in woodpecker cavities. Steeger and Machmer (1996) found that 54 percent of 28 bat roosts were in vacated woodpecker cavities, 32 percent in natural cavities, 11 percent in cracks, and the remainder under loose bark.



Figure 33—A woodpecker nest cavity excavated in the decayed sapwood of a ponderosa pine snag; the heartwood can be too sound for excavation. Most other tree species have sapwood that is too thin to accommodate a nest, so nests are usually excavated in the decayed heartwood.

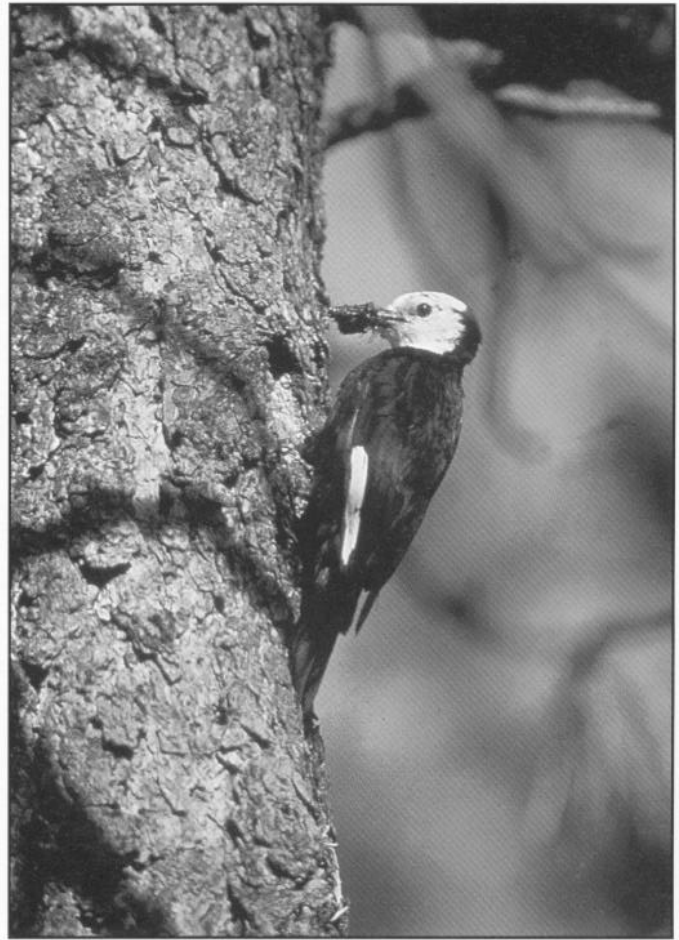


Figure 34—Woodpeckers, including this white-headed woodpecker, typically excavate nest cavities in dead trees.



Figure 35—The red-breasted nuthatch (*Sitta canadensis*) requires extensively decayed wood for cavity excavation.



Figure 36—Bats often roost under loose bark and in woodpecker cavities.

Because owls do not build nests, the smaller owls use existing cavities (fig. 37), and the larger forest owls use platforms. Snags with broken tops often provide nest platforms for great gray (fig. 38) great horned, and barred (*Strix varia*) owls.

Snags are used by some woodpeckers for foraging. Pileated woodpeckers forage extensively in the interior wood of snags in search of carpenter ants (*Camponotus* spp.) (fig. 39). Hairy (*Picoides villosus*), black-backed, three-toed (*P. tridactylus*), and white-headed woodpeckers all forage extensively on dead trees, particularly on insects in the bark, cambium, and sapwood (fig. 40).

Decay Process

Tree species, size, and percentage of sapwood influence the rate of decay, as do environmental factors such as climate, elevation, and aspect. The group of decay fungi that colonize the sapwood of newly dead trees usually cause rapid decay. Trees killed by root disease, mistletoe infection, insect defoliation, drought, or flooding are likely to be colonized by sapwood rotting fungi and infested by bark beetles within 2 years after death. Trees killed by bark beetles often have considerable sapwood decay within a few years. Once the sapwood decay fungi (fig. 41) have decayed the newly dead sapwood entirely, they often are replaced by saprophytic fungi, a large group of general scavengers (figs. 42 and 43). The saprophytic fungi continue to decompose the sapwood and then proceed at a slower rate into the heartwood. Heart-rot fungi that may already be present in the trees at the time of death usually are relatively inactive and contribute little to the deterioration of the dead tree. The thin layer of decayed sapwood in Douglas-fir (fig. 44) contrasts with the thick layer of sapwood in ponderosa pine (fig. 33). Cavity nesters readily excavate cavities in the thick sapwood of ponderosa pine snags because it is softened by decay.

Stain-causing fungi (that is, "blue stains") often are associated with beetle and woodborer infestation. The stain fungi do not cause decay, or softening, of the wood. They invade and use the cell contents, in contrast to the decay fungi, which use the structural components of the cell wall.

Trees killed by root disease typically add to the snag component for only a short time before they fall over. Root disease is caused by a group of decay fungi that infect roots and spread through root contact. Root disease pockets start in a tree or stump and tend to spread outward in all directions (Bega 1978). Typically, the tree dead for the longest time will be in the center and fringed by dying or recently dead trees on the outedge (fig. 45). Although snags created by root disease may not stand for a long time, the expansion of the center provides a continuous supply.

The rate of decay in trees killed by fire is influenced by the intensity of the fire, the rate of tree growth before the fire, the tree species, and its size. The sapwood and heartwood of true firs killed by fire deteriorates faster than in other species. The thin layer of sapwood in fire-killed Douglas-fir deteriorates rapidly, but the heartwood decays more slowly than in other

species. The extremely thick sapwood of ponderosa pine, which ordinarily constitutes from 50 to 75 percent of the tree's volume, is more resistant to general deterioration than is the sapwood of other species. The sapwood of fire-killed ponderosa pine begins to soften in the third year after death (Kimmey 1955).

Selecting Snags

Characteristics to consider when selecting snags for retention are tree species, diameter, height, structural class, and proximity to other snags and live trees. The kind of snags retained depends on management objectives and the snag resource available. For example, if the objective is to leave rest sites for martens, then hollow grand fir and western larch snags would be retained. If the objective is to provide nesting habitat for large forest owls, large-diameter snags with broken tops would be retained. To provide habitat for all cavity nesters, a variety of tree species would be retained for both foraging and nesting.

Tree species-Retention of snag species depends on the objective and the geographic area. In Montana, McClelland and others (1979) found that western larch, ponderosa pine, paper birch, and quaking aspen are preferred for nesting by cavity-using birds. Douglas-fir was used for foraging rather than nesting. Another study in Montana showed that red-naped sapsuckers used paper birch (5.16 percent of nest trees), western larch (35.5 percent), quaking aspen (6.5 percent), and Douglas-fir (6.5 percent) for nest sites (Tobalske 1992). In interior cedar-hemlock (*Tsuga heterophylla*) stands in southern British Columbia, 85 percent of 237 nests of cavity-using birds, 14 cavity-using mammals, and 31 bat nurseries were in Douglas-fir, quaking aspen, paper birch, and western larch (Steege and Machmer 1995). All nests excavated by black-backed ($n = 35$ nests) and three-toed ($n = 20$) woodpeckers in a study in central Oregon were in lodgepole pine (Goggans and others 1988).

In central Oregon, Bate (1995) reported that woodpeckers prefer ponderosa pine snags over lodgepole pine snags for nesting. Dixon (1995) also reported a nesting preference for ponderosa pine snags by white-headed woodpeckers. In northeastern Oregon, ponderosa pine and western larch were favored as nest trees by pileated woodpeckers and Williamson's sapsuckers; most nest trees used by hairy and black-backed woodpeckers and northern flickers were in ponderosa pine trees (Bull 1986). In east-central Washington, woodpeckers selected ponderosa pine and Douglas-fir for nest cavities and western larch and Douglas-fir for feeding (Bevis 1996).

When retaining snags for cavity nesters, ponderosa pine, western larch, quaking aspen, and paper birch are the favored species in many localities. Suitability of other species must be determined based on known wildlife use and decay conditions characteristic of each tree species for each locality. For hollow snags, grand fir is the best species to retain in the interior Columbia River basin.

Tree size and height-Typically, large-diameter snags (more than 20 inches d.b.h.) stand the longest, can accommodate nest cavities of any woodpecker species, and provide



Figure 37—Small owls, like this saw-whet owl, require an existing cavity for nesting.



Figure 38—Great gray owls, as well as some other large owls, may use the broken tops of snags for nesting.



Figure 39—Pileated woodpeckers, in search of carpenter ants and other invertebrates, excavate large rectangular cavities in the heartwood of some snags and logs.



Figure 40—Hairy, black-backed, and three-toed woodpeckers forage for invertebrates in the bark of snags.

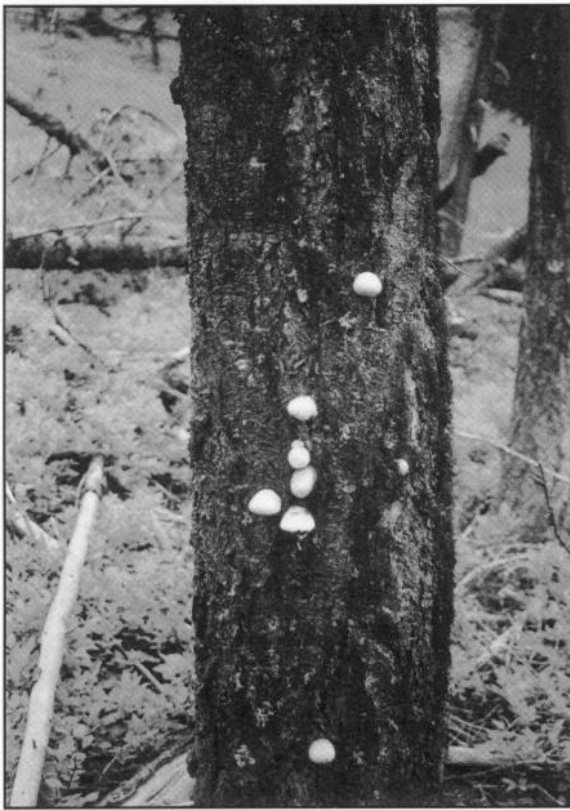


Figure 41—The pouch fungus (*Cryptoporus volvatus*), a sapwood decay fungus, typically invades and fruits on trees soon after their death (up to, but not longer than 18 months).

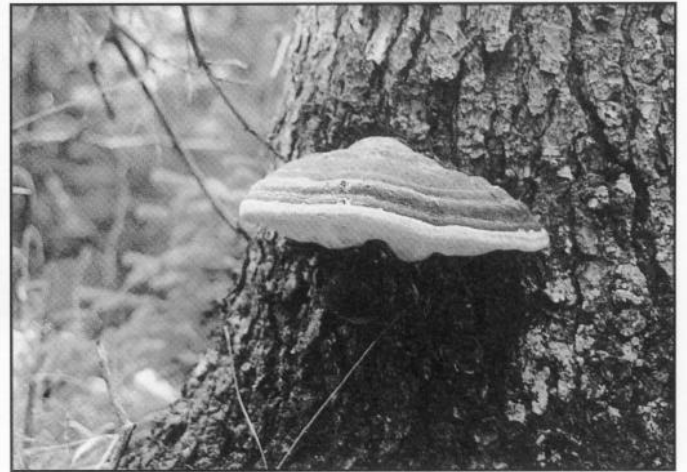


Figure 42—The red belt fungus (*Fomitopsis pinicola*), a saprophyte, is one of the most common fruiting bodies found on snags and logs.



Photo by Craig Schmitt

Figure 43—Fruiting bodies of many other saprophytic fungi commonly are seen on logs, because the moisture conditions are conducive to decay and formation of fruiting bodies.



Figure 44—A Douglas-fir killed by insects; the sapwood is extensively decayed, and the heartwood is sound.



Figure 45—Root diseases start in a tree or stump and spread slowly outward in all directions. Disease pockets typically have the oldest snags in the center with a fringe of dying trees. Trees in root disease pockets may not stand long because of root decay.

the most stable microclimate because of the wood thickness. Preference for large-diameter snags has been well documented for the pileated woodpecker, hairy woodpecker, northern flicker, and Williamson's sapsucker in northeastern Oregon (Bull 1986); for the white-headed woodpecker in central Oregon (Dixon 1995); for woodpeckers in ponderosa pine forests in central Oregon (Bate 1995); for pileated woodpeckers in Montana (McClelland and others 1979); and for cavity nesters as a group in burned ponderosa pine forests of southwestern Idaho (Saab and Dudley 1997).

Thickness of the wood surrounding a cavity is important for thermal regulation and protection from predators. Woodpeckers that nest or roost in small trees may have only a thin shell of sapwood or only bark surrounding their cavity, which provides minimal insulation and protection against predators. Black bears, martens, or raccoons (*Procyon lotor*) can break into a nest cavity if the shell surrounding it is too thin.

Although most cavity nesters select for the largest snags available, a few species seem to prefer smaller trees in some localities. Downy (*Picoides pubescens*) and three-toed woodpeckers prefer smaller trees for nesting in Montana (McClelland and others 1979). Black-backed woodpeckers use relatively small, hard snags in areas with stand-replacing fires in ponderosa pine/Douglas-fir stands in Idaho (Saab and Dudley 1997).

Height is also important in selecting snags because different species of woodpeckers prefer to nest at specific heights (Thomas and others 1979). Pileated woodpeckers typically nest 30 to 50 feet above the ground. To have enough girth at these heights to accommodate cavities that are 8 to 10 inches wide and 24 inches deep takes a large tree. Although some woodpeckers will nest within 3 feet of the ground, these nests are more vulnerable to predators (Li and Martin 1991) because they are easily detected.

In addition, the larger and taller snags have greater volume and are more likely to have the appropriate decay conditions at the preferred height than are smaller trees. Therefore, when possible, managers should retain the largest snags available.

Snag structural classes—The physical appearance of snags is largely indicative of the condition of the wood, so appearance is the basis for snag selection. Thomas and others (1979) presented nine successional stages from the time of death to total decomposition of a tree. Here we present a simplification of the successional stages and classify all snags into three structural classes (figs. 46 and 47). When retaining snags, all structural classes should be represented across the landscape.

Snag structural class 1 represents those snags that have recently died, typically have little decay, and retain their bark, branches, and top. These snags are used extensively by woodpeckers for foraging in and under the bark.

Snag structural class 2 represents those snags that show some evidence of decay and have lost some bark and branches, and often a portion of the top. Most nesting by woodpeckers, as well as extensive foraging in and under the bark and in the interior of the wood, is in this structural class. Remaining bark that has loosened can provide nest sites for brown creepers or roost sites for bats.

Snag structural class 3 represents those snags that have extensive decay, are missing the bark and most of the branches, and have a broken top. Structural classes for grand fir and Douglas-fir must be modified to some degree because they tend to retain their bark. Foraging in the interior wood is the primary activity in these extensively decayed snags. Secondary cavity users also may nest in existing cavities originally excavated by woodpeckers. Weaker excavators like northern flickers and Lewis' woodpeckers (*Melanerpes lewis*) excavate nests in extensively decayed wood characteristic of this structural class.

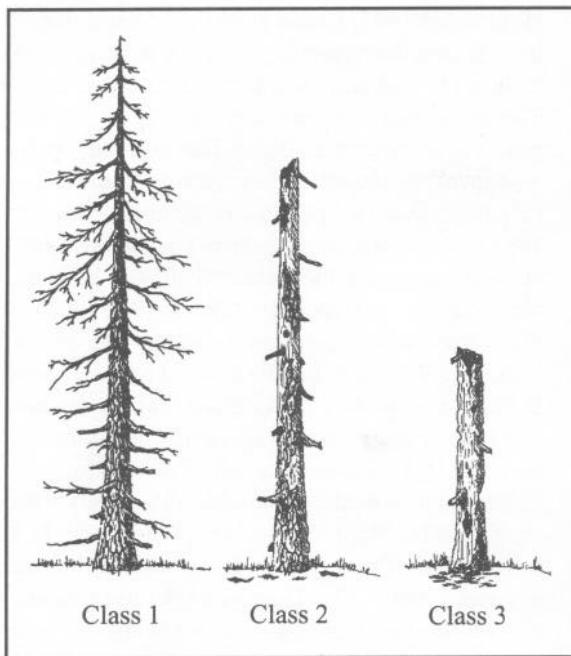
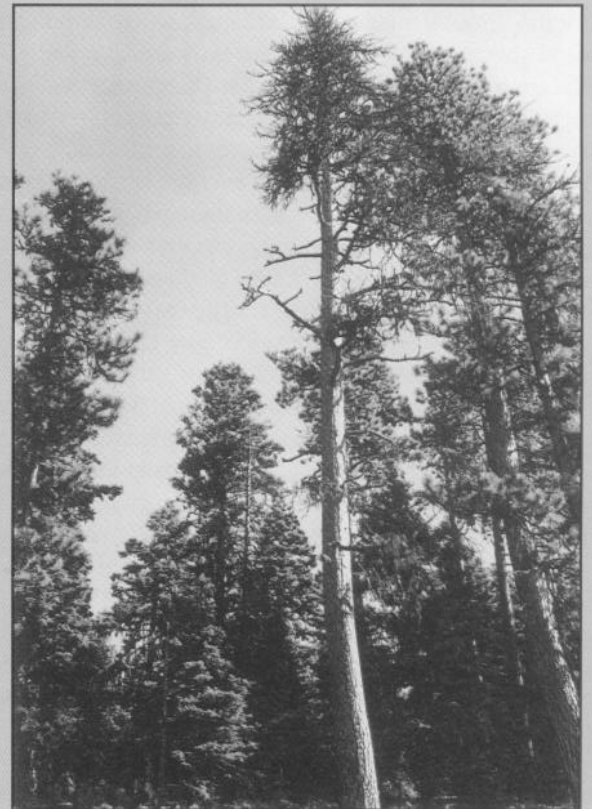


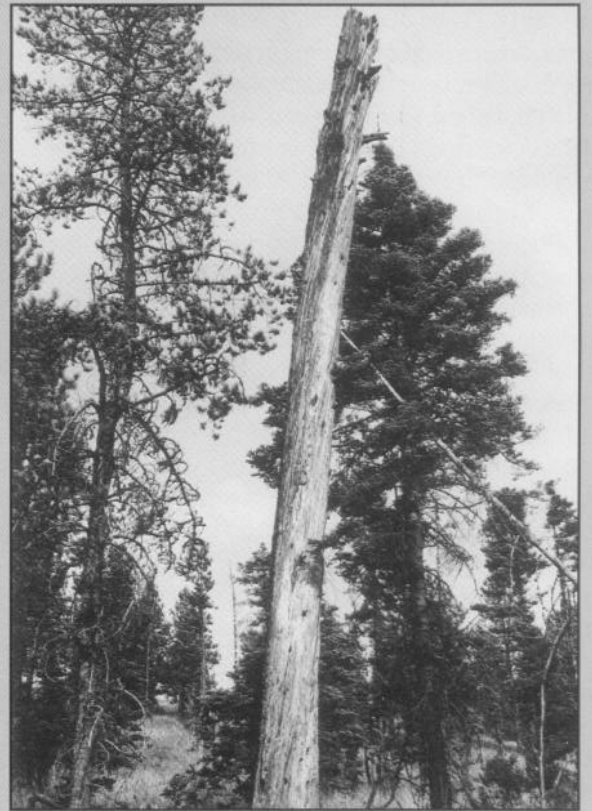
Figure 46—Three structural classes of dead trees.



Class 1



Class 2



Class 3

Figure 47—Three structural classes of dead trees.

Snag distribution -- Snags can either be left in clusters or scattered across the landscape, although where to retain them depends largely on where they currently are. Typically, snags are in clumps naturally because the agents of disease, insects, fire, or flooding that kill many trees act in a localized area. Clusters of snags may be easier to protect during management activities than snags evenly distributed across the landscape. Worker safety is an issue when harvesting adjacent to snags. Retaining snags in clusters, as well as the live trees between the snags, keeps workers away from snags and provides canopy cover for wildlife using the snags.

Two studies on woodpecker use of snag clusters reported different results. No difference was found between woodpecker use of snag clusters versus scattered snags in western Oregon (Chambers 1997). In areas where stand-replacement fires had burned in ponderosa pine/Douglas-fir stands in Idaho, Saab and Dudley (1997) found that cavity nesters as a group select clusters of snags for nest sites instead of evenly spaced trees.

Most studies recommend managing snags in every 5- to 25-acre patch (Bate 1995, Evans and Martens 1995). Because woodpeckers are territorial, only one pair of each species occupies the same territory; therefore, to attain the maximum density of cavity nesters, snags need to be distributed across the landscape.

In addition, retaining snags on all aspects and on all positions of the slope ensures habitat availability for wildlife species with different preferences. For example, pileated woodpeckers tend to roost in draws during summer but roost higher on slopes in winter (Bull and others 1992). Martens rest or travel in riparian areas a third of the time in summer but only half that often in winter; upper slopes are used half the time in winter but only a third of the time in summer (Bull 1995).

Retaining snags close to living trees provides cover for cavity users. If snags are retained in the middle of a clearcut, species like northern flickers, Lewis' woodpeckers, bluebirds, and American kestrels (*Falco sparverius*) will use them for nesting, but most other woodpeckers will not nest in open areas.

In many areas, fuel-wood cutters are likely to remove snags along roads. This potential problem can be remedied by not leaving snags in areas that are accessible to fuel-wood cutters or by not counting snags left adjacent to accessible roads toward the number retained for a particular stand.

In summary, wherever the objective is to provide viable populations of primary and secondary cavity nesters, prudent managers will provide large-diameter snags when available, snags in a variety of structural classes, snags in every 5- to 25-acre stand and in clusters if available, and snags on all slope aspects and positions of the slope, and adjacent to green trees.

Snag densities-Limited information is available on numbers of snags to retain for wildlife species in the interior Columbia River basin (Bate 1995, Bull and Holthausen 1993, Dixon 1995, Evans and Martens 1995) (table 1). The guide most widely used in the past, Thomas and others (1979), prescribed the number of nest and roost trees to leave for specified woodpecker populations, but the number was based on a hypothetical, untested model and did not include any snags for foraging. Three studies (Bate 1995, Bull and

Holthausen 1993, Dixon 1995) conducted in eastern Oregon have shown that retaining foraging structure is essential, in addition to nest and roost trees in managed landscapes. The Thomas model provided only two roost trees per pair per year, yet research has shown that individual pairs of pileated woodpeckers and white-headed woodpeckers use considerably more than two per year (Bull and others 1992, Dixon 1995). Radio-telemetry studies have shown that home range sizes of pileated woodpeckers (Bull and Holthausen 1993), white-headed woodpeckers (Dixon 1995), and three-toed and black-backed woodpeckers (Goggans and others 1988) are considerably larger than those used in the Thomas model. Raphael and White (1984) found that the relation between numbers of snags and cavity nesters is not linear, which was assumed in the Thomas model. The substitution factor used in the Thomas model is variable and largely a function of snag density. Neitro and others (1985) thought allowing substitution of snags that reduced the number retained was not appropriate. The Thomas model did not take into account the habitat needs of some of the secondary cavity nesters, like bats and brown creepers, that use such snag features as loose bark. In addition, Bull and Holthausen (1993) found lower densities of pileated woodpeckers in nine study areas than predicted by Thomas and others (1979) based on the number of snags present. The above studies present new data suggesting that some of the assumptions and data used in the Thomas model are not valid, and that the prescribed snag densities need to be revised upward.

We know of only three studies in the interior Columbia River basin that have calculated both the density of snags and woodpeckers in managed and unmanaged landscapes. Bate (1995) used six study areas in ponderosa pine stands and found woodpecker abundance was best predicted by hard snag density, large green tree density, canopy height, and number of canopy layers. Of the nine study areas, only one represented a relatively unmanaged forest with the number of snags that probably approximated historical ones. In this stand, Bate found 3.8 snags greater than 10 inches d.b.h., and 60 percent were larger than 20 inches d.b.h. These snag numbers supported 32.3 woodpeckers per 247 acres and represented the study area that most likely supported viable populations of cavity nesters. Dixon (1995) found similar results in some of the same study areas Bate used.

Another study relating woodpecker density to snag density was conducted in northeastern Oregon (Bull and Holthausen 1993). The two study areas that contained viable populations of pileated woodpeckers had an average of 4.2 and 3.8 snags (10 inches or larger d.b.h.) per acre and 0.5 and 0.4 nesting pairs per 247 acres, respectively. The two study areas were in lightly managed landscapes predominated by mixed-coniferous stands with a high density of logs.

Evans and Martens (1995) recommended densities of snags for retention on the Payette National Forest based on their ecological value, encompassing soil health, seedling regeneration, moisture retention, nutrient recycling, and wildlife use (table 1). The numbers that they recommended were derived from actual snag numbers identified during

timber inventory and vegetation plots but were scaled down to the lower ranges of the snag numbers for the recommendations and include snags 10 inches d.b.h. and larger.

Ideally, data would be available on the exact number of snags required to support specific populations of primary and secondary cavity nesters. Unfortunately, this kind of information is not available. We do know, however, that the snag numbers presented by Thomas and others (1979) are not adequate to support the populations intended because of a lack of foraging strata and invalid assumptions used in the model. If management agencies have an objective to manage for viable populations of woodpeckers, providing numbers of snags that have been shown to support viable populations in the recent studies would be prudent.

Although snags are the key structure typically focused on for cavity nesters, realizing the importance of the forest surrounding the snags also is essential. Some species like the pileated and white-headed woodpeckers and American martens are associated with older forests. For white-headed woodpeckers, the snags must be in association with large-diameter ponderosa pines. For pileated woodpeckers and martens, logs, large-diameter green trees, and a dense canopy are needed. Leaving large-diameter snags or green trees in younger forests, also has value as providing biological legacies.

Snag retention in burns-The above management implications apply to healthy green stands. With vast areas of Oregon, Washington, and Idaho burned by wildfires in the 1990s, there is much interest in determining numbers of snags to retain in burned areas after harvesting. Saab and Dudley (1997) reported that woodpeckers selected nest sites with snag densities greater than those measured at random sites in ponderosa pine/Douglas-fir forests with stand-replacing fires. From 10 to 14 snags per acre were retained in burned stands that were harvested; about 38 to 42 snags per acre were in the unharvested burned stands. Seven species of cavity nesters using the burned stands selected nest sites with more than 20 snags per acre, where snags were distributed in clumps. Lewis' and white-headed woodpeckers, and American kestrels selected the largest, most heavily decayed snags available for nesting. Evans and Martens (1995) presented recommendations for numbers of snags to leave in burned stands.

Green tree replacements-Snags are a dynamic resource; old snags fall and living trees die to become new snags. Snag-dependent wildlife need a continuous supply of snags over time. To provide a continuum of snag habitat, future snags must be planned for by leaving green trees to eventually become snags in managed stands. To determine the number of green tree replacements, information on fall rate of standing snags, snag density, live stem density, and mortality rate of live stems is required. Various models have been developed to calculate the number of green trees to provide for recruitment when specific stand inventory information is available (Bull and others 1980, Cimon 1983, Schommer and others 1993). If snags are to be created by killing green trees when the stand becomes snag deficient, the number of green trees required is less because the manager does not have to rely on natural mortality to replace

those snags that fall. Creating snags is costly, however, and stands are seldom monitored to determine when trees need to be killed.

Snag Longevity

Snag longevity, or the amount of time a snag stands, is essential information for managing the snag resource. The length of time snags stand is a primary factor in determining the number of green tree replacements needed to maintain a specific snag density over time. Snag longevity is a function of many factors including species, diameter and height, percentage of heartwood, cause of death, soil type and moisture, forest type, and prevalence of windstorms. Because so many factors influence how long a snag stands, fall rates should be determined by species and size class on each management area. Listed below are studies that report snag fall rates. When possible, the amount of time when 50 percent of snags in a particular study have fallen will be reported.

Several studies have reported fall rates of beetle-killed ponderosa pine. Keen (1955) reported that 50 percent of the ponderosa pines in southern Oregon and northeastern California fell 9 to 10 years after death on pumice soils and 6 to 7 years after death on loam soils. The percentages of snags that fell after 7 years by diameter class, are presented in the following tabulation:

Diameter class (inches)	Percentage
10-18	75
20-28	65
30-38	50
40-48	35
> 50	30

Most of the beetle-killed ponderosa pines in Colorado fall between 7 and 10 years after infestation (Schmid and others 1985). Trees were 7 to 22 inches d.b.h.

In northeastern Oregon, half the ponderosa pines less than 10 inches d.b.h. fell 7 to 8 years after death and half those 10 to 19 inches d.b.h. fell after 8 to 9 years (Bull 1983). Beetle-killed lodgepole pines have similar fall rates, with half of those less than 10 inches d.b.h. falling within 6 to 7 years and half of those 10 inches and larger falling after 7 to 8 years (Bull 1983). In a second study in northeastern Oregon (Bull and Partridge 1986), half of the ponderosa pine snags less than 20 inches d.b.h. fell after 6 years; half of the ponderosa pine snags 20 inches and larger fell after 9 years.

Beetle-killed spruce in Colorado stood much longer than ponderosa pines reported in the studies above. Mielke (1950) found that 84 percent of beetle-killed spruce remain standing after 25 years. Hinds and others (1965) found that 72 percent of beetle-killed spruce remain standing after 20 years.

Fire-killed snags may or may not stand longer than beetle-killed snags, depending on the area. Dahms (1949) reported that a little over half the ponderosa pine snags are down 10 years after a fire in central Oregon. In Montana, nearly half of all lodgepole pine snags fall by the fifth season (Lyon 1977). In California, Kimmey (1955) described the

breakup of a fire-killed stand, although specific fall rates were not presented. In the fourth and fifth year after the fire, many ponderosa and Jeffrey pine (*Pinus jeffreyi*) broke off at the ground or up to 50 feet above the ground. By the fifth year, the general breakup continued until only scattered barkless snags and stubs remain.

In northeastern Oregon, different methods of killing ponderosa pines were investigated (Bull 1996c, Bull and Partridge 1986). Trees that had been topped stand the longest; half of those less than 20 inches d.b.h. are down after 10 to 12 years; half of those 20 inches or larger are down after 12 to 17 years. Half the trees injected with a silvicide are down 7 years after treatment. Half the girdled trees are down 9 years after treatment.

Fall rates of snags that have been created differ. Ponderosa pines infected with dwarf mistletoe were frilled and poisoned with an herbicide in the Southwest; after 10 years, 95 percent of those trees are down (Fairweather 1995).

All of these studies suggest that most ponderosa pine and lodgepole pine that died from fire or beetles in the interior Columbia River basin have fall rates of less than 10 years. Small-diameter snags fall sooner than do larger ones.

Sampling Techniques

Knowledge of snag density is essential for managing forest stands effectively, as well as for complying with standards and guidelines. Various methods have been used to determine snag densities: area-wide counts, fixed-radius circular plots, variable-radius plots using prisms (Bull and others 1990), and variable-strip transects (Bate and others, in press). Total counts of snags over large areas are very time-consuming but yield the most accurate density information. Fixed-radius plots typically need to be at least 1 acre because snags are usually scarce and variance is high. Many plots are usually required to accurately estimate snag density.

Bate and others (in preparation) have developed a more efficient method of sampling snags than either area-wide counts or fixed-radius plots: data are collected from a pilot sample transect and used in a computer program. The program determines the optimal length and width of a strip transect within a given area; the optimal size is that which minimizes the cost and variance. The program then provides the necessary sample size to obtain a snag density within the desired statistical bounds. Transect lengths are either 164 or 328 feet; transect widths range from 33 to 131 feet. The

Table I-Density of snags reported or recommended in four areas; numbers are snags per acre larger than 10 inches d.b.h. (unless otherwise stated), and the percentages represent snags larger than 20 inches d.b.h.

Forest type	Locality			
	Western Idaho ^a	Central Oregon ^b	Northeast Oregon ^c	North-central Idaho ^d
Ponderosa pine:				
Open canopy ^e	1.6(75%)			
Closed canopy ^f	4.8(44%)	4(60%)		
Mixed conifer:				
Open canopy	2.5(72%)			
Closed canopy	9.0(39%)		3.8(29%)	10-48
Lodgepole pine:				
Open canopy	4.5			
Closed canopy	7.7			
Spruce/fir	9.5(21%)			

^a Recommendations for snag densities selected from the lower ranges of snag numbers on timber inventory plots and fixed-radius plots on the Payette National Forest; different snag levels recommended for burned and unburned stands (Evans and Martens 1995).

^b Snag numbers based on variable-width transects conducted in an unmanaged stand of old growth in central Oregon where woodcutting was prohibited (Bate 1995).

^c Numbers based on density of snags in two 4,000-acre study areas in northeastern Oregon that supported viable numbers of pileated woodpeckers; areas had some timber harvest but no woodcutting (Bull and Holthausen 1993).

^d Densities based on timber inventory plots in unmanaged stands of large saw timber. The snag density varied depending on what snags were included in the count. The 10 snags per acre included only snags 15 inches d.b.h. or larger and 50 feet or taller.

The 48 snags per acre included all snags 15 inches d.b.h. or larger of any height. Western white pine snags were not counted (Craig 1995).

^e Stands with less than 30 percent canopy closure.

^f Stands with more than 30 percent canopy closure.

program also provides a “distribution index,” which is an estimate of the percentage of the sampled landscape supporting target snags or trees.

Creating Wildlife Trees

In managed stands, retaining existing snags is the most ecologically sound and economical approach to providing wildlife trees. If stands are devoid of snags, however, an option is to alter or kill living trees. Depending on the method used, killing trees can be costly and may not produce the desired decay conditions. Years may pass before the decay is sufficiently advanced to promote cavity-nester excavations.

Bull and Partridge (1986) investigated six methods of killing ponderosa pine. They determined that topping trees with either a chainsaw or explosives produced snags that stood the longest and received the greatest nest use by woodpeckers (figs. 48 and 49). In this study, girdling, fungal inoculation, and beetles attracted by pheromones did not consistently kill the tree. Trees killed by girdling or silvicides fell over too quickly to provide wildlife nest trees.

In a study in New Mexico, all of the ponderosa pines killed by girdling were used for foraging by woodpeckers. Most of the trees greater than 16 inches d.b.h. were standing after 7 years, and about 30 percent contained woodpecker nest sites (Parks 1996b). Because the climate in the New Mexico sites is drier than in the Oregon study area used by Bull and Partridge (1986), basal decay of killed trees may have been less, so the trees stood longer.

Recent work by Parks and others (1996a, 1996b) documents a new method of inoculating live trees with decay fungi. Six years after inoculation of 60 living western larch, 14 percent contained woodpecker cavities near the point of inoculation. These trees may remain alive for decades with a pocket of decay that woodpeckers can use for nesting. Trees may be logged next to these trees without safety concerns, and live trees are less likely than dead trees to be lost to fuel-wood cutters. These preliminary results for western larch suggest that inoculation produces desirable wildlife trees at a lesser cost than killing trees to create snags.

A variety of wildlife tree structures can be created with a chainsaw in standing, living trees. Trees can be topped leaving a horizontal branch structure on which ospreys (*Pandion haliaetus*) can build nests (fig. 50). A depression can be cut into the top of a tree that has been topped to produce a nest site for great gray owls (fig. 51). Artificial cavities and hollows can be cut into standing and downed trees (figs. 52, 53, and 54). Slits can be cut into trees to create roosting habitat for bats (fig. 55). These techniques and others are described by Brown (1996).

Three primary considerations in creating wildlife trees are the target wildlife species for which the structure is being created; the tree species, size of tree, and habitat locality most likely to be used by the targeted wildlife species; and the method of altering or killing trees that is most likely to produce long-standing trees in a given geographic area. Rainfall, snowfall, incidence of windstorms, and prevalent decay organisms all must be considered.

Thousands of trees have been killed to create snags in the interior Columbia River basin in the last 15 years. Few of them have been monitored, however, to determine whether long-lasting, quality snags were actually produced. Because climate and decay organisms differ with area, results of management activities, such as snag creation, must be monitored to ensure that results warrant the cost of these treatments. We include a data form to monitor wildlife use of created snags in appendix A.

Review

- Ponderosa pine, western larch, quaking aspen, and paper birch are favored tree species for nest sites of woodpeckers in many areas in the interior Columbia River basin.
- Large-diameter snags provide nest habitat for the greatest variety of cavity nesters and stand longer than smaller snags.
- Snags can be classed into three structural classes that are a simplified version of past decay class categories.
- Snags should be provided in every 5- to 25-acre stand, in clusters if available, on all slope aspects and positions of the slope, and adjacent to green trees.
- Recent studies have shown that the snag model developed by Thomas and others (1979) did not accurately predict woodpecker abundance based on snag abundance. New information suggests that foraging strata (snags and other structures) must be incorporated into any snag model, and that snag numbers need to be revised upward.
- Published data suggest that populations of cavity nesters were viable in stands of ponderosa pine and mixed-conifer forests that contained about four snags per acre, a large component of old-growth stands, and abundant logs.
- Snags can be retained over time by using models for green tree replacements.
- Snag longevity depends on cause of death, tree species, diameter, height, amount of heartwood, geographic area, and site conditions.
- Creating snags and other wildlife structures can mitigate the loss of natural habitat, but retaining existing structures is most cost effective and ecologically sound.

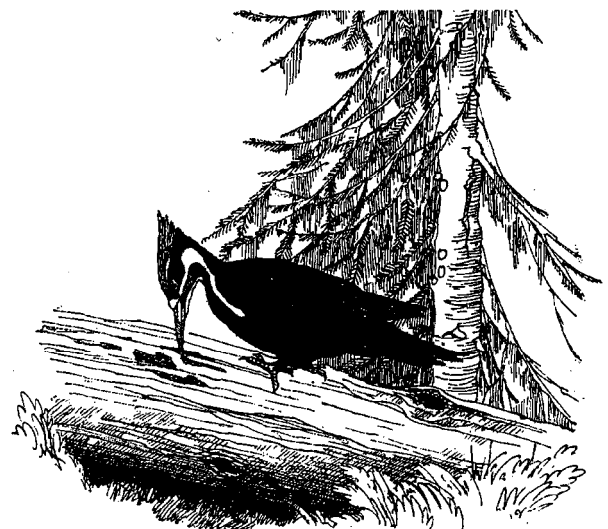




Figure 48—Ponderosa pine snags created by topping received the greatest amount of woodpecker nest use in eastern Oregon.

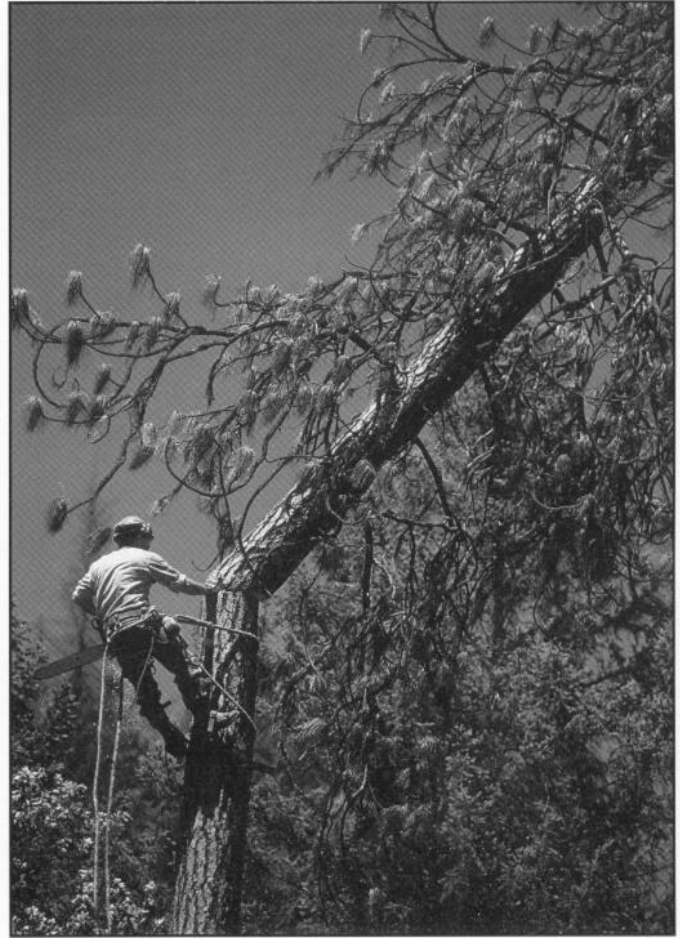


Figure 49—A ponderosa pine being topped to create a snag.



Photo by Timothy Brown

Figure 50—Topped trees with a platform provide nest sites for ospreys.

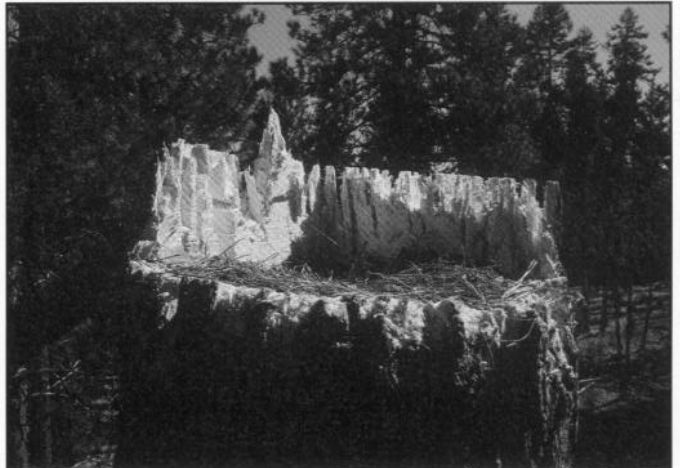


Photo by Timothy Brown

Figure 51—This nest site for great gray owls was created by topping a tree and cutting a depression in the top of it.



Photo by Timothy Brown

Figure 52—This artificial cavity was made by removing a block of wood and fashioning a face piece with an entrance hole.

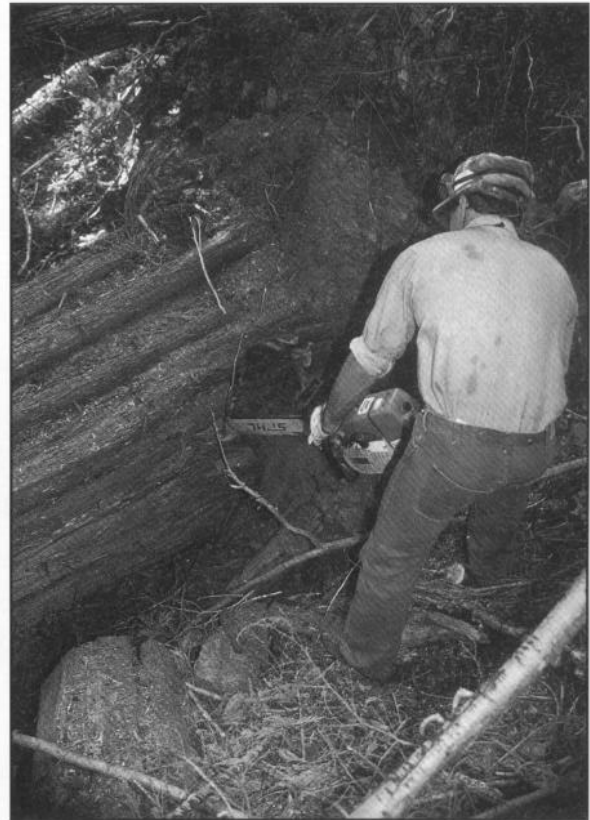


Photo by Timothy Brown

Figure 53—Cutting a hole into a hollow western redcedar log allows access by wildlife.



Photo by Timothy Brown

Figure 54—Chainsaws can be used to create hollow chambers in logs.



Photo by Timothy Brown

Figure 55—Slits cut into trees provide roost sites for bats.



LOGS



Ecological Processes and Functions

The natural fate of all living trees is to become part of the down-wood component on the forest floor. Characteristics of the living and dead standing component in a stand determine the species and physical attributes of the material that falls to the ground. Late-successional stands typically have large-diameter logs on the forest floor recruited from the wood resources in the standing trees through a variety of natural processes such as breakage; falling trees; and transport caused by snow-loading, windstorms, avalanches, debris flows, fires, and floods. Other natural processes such as the activity of insects and diseases that kill or physically weaken trees likewise contribute dead wood to the forest floor. All these factors can directly or indirectly result in death and falling of individual branches, tops, or whole trees. Stands or patches of trees and landscape-scale tree mortality are common events in the history of forest ecosystems. All of these mortality and decay processes are natural and necessary; they contribute to the nutrient reserves and physical and chemical characteristics of soils in healthy forests. Thus, dead wood in all its forms is a fundamental feature of healthy forests.

The “life” or persistence through time of dead trees, especially large ones, can last several decades. Over a period of possibly a century, logs serve as a source of organic and inorganic nutrients and chemical components in soil development. The constituents contributed by logs enrich the soil and improve its structural properties, allowing plant growth. Logs contribute to the water economy of a site and provide microhabitats that protect wood-dwelling organisms with moist, thermally stable, predator-protected niches in which to live. Logs in or near streams, ponds, or lakes provide structure for amphibians, beaver, mink, otter, and birds (Lofroth, in press; Maser and Trappe 1984).

Organisms representing a broad array of plants, invertebrates, and vertebrates use log habitats in forests. From microscopic protozoa and fungi to wildlife and roots of large trees, down wood teems with life. Many of these organisms are connected by functional pathways that are partially or completely unknown. For both simple and complex plants

and animals, down wood in all its forms represents a rich substrate on which they feed and live.

We use the term “logs” for down woody material such as trees, branches, or tops that have fallen to the forest floor. The minimum piece-size to qualify as a log has a large-end diameter of 6 or more inches and a length of 8 or more feet. A leaning snag that forms less than a 45° angle with the ground is considered a log. Most logs touch the forest floor, but sometimes they fall like jackstraws and are supported above ground by other logs (fig. 56).

Logs can be considered as either places animals forage or places that afford them protection. Insect-eating, fungus-eating, wood-eating, and predaceous animals find rich and varied sources of food in and associated with logs. Besides hiding cover and protection, logs provide physically complex structures where animals find stable temperatures and moisture for nesting, denning, feeding, and food storage. Logs also serve as places for sunning and as lookout posts. Spruce grouse (*Dendragapus canadensis*) regularly sit on logs sites where they are apparently better able to avoid predation. In spring, males use these elevated sites as walkways for their displays (Harrison 1996).

Small mammals use logs extensively as runways. This association between log structure and small mammals was apparent in studies of radio-tagged great gray owls. Nearly 80 percent of the time, down wood was within 3 feet of where great gray owls captured or attempted to capture prey (fig. 57) (Bull and Henjum 1990). Maser and others (1979) described wildlife uses of logs in relation to log decomposition class, size, age, log species, and distribution. They described processes that lead to increased and more varied uses of logs by wildlife, plants, and invertebrates as logs decompose. Lofroth (in press) reviewed literature that further describes wildlife uses of logs, including log habitats under snow.

The size, distribution, and orientation of logs are more important to wildlife than are the tonnage or volume, as used in characterizing woody fuels (Maxwell and Ward 1980). In general, specific wildlife uses are correlated with log size.

The smaller logs benefit small mammals, amphibians, and reptiles, for which they function primarily as escape cover and shelter when the animal can get inside or under the log (fig. 58). Large-diameter logs, especially hollow ones, also benefit a variety of other vertebrates like martens, minks, coyotes, bobcats, cougars, and black bears (Lofroth 1993; Lofroth, in press; Maser and Trappe 1984) (fig. 59). Hollow logs are used by black bears for winter dens in some parts of their range. During late summer and fall, bears forage for invertebrates in logs (fig. 60). What percentage of their diet depends on this resource is not known, although it seems to be substantial based on current studies in northeastern Oregon (Henjum and Akenson 1996). Research on fishers (*Martes pennanti*) suggests that up to three dens may be used in rearing a litter. Although most dens are in cavities high in large (36-inch d.b.h.) living or dead trees, large logs also are used. In California and Montana study sites, one den was in a 36-foot log that was large enough to provide a convoluted 12-inch diameter cavity through its length; another den was in a 59-inch log of white fir (*Abies concolor*) (Powell and Zielinski 1994).

Lynx (*Lynx canadensis*) select dense, mature forested habitats that contain large logs and upturned stumps to provide security and thermal cover for kittens. In north-central Washington, lynx den in Engelnmann spruce/subalpine fir/lodgepole pine stands with high densities of downed trees supported 12 to 48 inches above the ground, which provide structure and diversity for denning and hunting (Koehler and Aubry 1994).

Distribution of logs influences wildlife use. Trees sometimes die in clumps or patches from diseases, insect activity, or fire. Mortality of this kind ultimately results in aggregations of logs. Within relatively continuous forested stands, however, logs appear fairly regularly. In late- and old-structure mixed-conifer stands in northeastern Oregon, we found that densities of logs fell within relatively close ranges; that is, standard errors were 8 to 18 percent of the means. These stands were not randomly selected stands, however, but were associated with pileated woodpecker home ranges (Bull and Holthausen 1993, Torgersen and Bull 1995).

Amounts and distribution of logs in managed landscapes have varied effects on wildlife and management strategies. Too many logs may impede travel by deer, elk, and cattle; they also may present increased fire hazard (fig. 56). Large numbers of logs afford excellent cover habitat for small vertebrates (fig. 56). Heavy accumulations of down woody debris can increase seed losses and damage to tree seedlings by squirrels, chipmunks, and mice, but these accumulations do not necessarily result in such damage. Research suggests that seedlings may actually be protected from grazing and scorching by the physical barrier and shading provided by down logs. Such protection often outweighs the negative effects of increased habitat for rodents and problems associated with them (Dimock 1974, Maser and others 1979). Orientation of logs can influence wildlife use. Logs that lie along the contours of a slope may be used more by wildlife than logs oriented across contours, especially on steep slopes.

Soil and organic debris that accumulate along the upslope side of a log encourage seedlings to establish and grow, which in turn attract invertebrates and small vertebrates that find more diverse structure and niches for activity (Maser and Trappe 1984).

Large numbers of down trees can form a maze of logs, many of which may be supported 2 or more feet above the ground by other logs. Patches of these jackstrawed logs often are found in late- or old-structured stands of lodgepole pine, Engelmann spruce, subalpine fir, and grand fir. Although such conditions may represent a significant fire hazard, they also provide critical structures for some animals. Marten, mink, and cougar hunt in them; when snow covers the logs, a complex array of snow-free spaces and runways provide important habitat for protection and foraging by martens, fishers, and small mammals under the snow. Tree squirrels also spend much of the winter in this environment, where they feed on seeds from cached cones.

Slash piles remaining after harvest can benefit some wildlife like rodents, hares, and rabbits (fig. 61). Increased commercial markets for chips and firewood have increased demand on this component of wildlife habitat. No completely researched guidelines exist for distributing logs and woody debris in managed stands. Although quantitative, spatial, and functional relations are still poorly understood, that does not make any single component or feature of distribution any less important (Bartels and others 1985, Maser and others 1979).

Decay Process

The decay of logs is continuous; some decay may begin even before a tree dies. The rate and patterns of decay and the decay organisms depend on many dynamic factors. Did the down log derive from a fallen snag or a living tree? If the log came from a snag, what killed the tree? How big is the log? Is it a long, small-diameter log or a short, large-diameter log?

Every living tree is composed of tissues that perform specific functions and have different structures to accomplish these functions. These tissue-substrates continue to provide different environments in logs over many years for a host of microbes, higher plants, and invertebrates. The succession of decay-related organisms in turn produces a continuum of decayed wood with many different structural and textural characteristics.

Hollow logs are an example of a particularly important structural category. Logs do not become hollow on the ground; they are hollow because of the action of heart-rot fungi that occurred when the tree was alive. Such hollow trees ultimately die and fall to the forest floor (fig. 59).

The physical setting in which the log resides also affects the decay process. Slope, aspect, exposure to sunlight, elevation, and the degree to which the log is in contact with the ground all influence the characteristics of decay. Even orientation of the log can influence decay: logs that are oriented along the contours of a slope accumulate soil and debris against the uphill side, which holds moisture and hastens some decay processes. Charring of logs can hamper excavation by some invertebrates and vertebrates for many